ELECTROCHEMICAL DEBURRING: ANOTHER SHARP SWORD

IN THE BATTLE WITH BURRS

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In industry's continuing struggle with burrs, several cost reducing approaches have been largely overlooked. Electrochemical Deburring (ECD) is one of these processes. While this process has been used in the U.S. since 1962 and has been described briefly in over 100 publications, it has not received all the industry acceptance that most authorities feel it deserves.

PROCESS BASICS

As the name implies, this is a process which uses both electricity and chemistry to remove burrs. It is a very fast process suitable to a wide range of metals. It is one of the few processes which does not require a tool which cuts, scrapes, abrades, or otherwise touches the burr. Some of its best applications are with materials or configurations which are not easily deburred by any other process.

Consider for a moment the electroplating cell shown in Figure 1. When the switch is closed, current flows through the anode (item in solution which is attached to "+" side of battery or power supply) and into the liquid solution. Since most liquids conduct electricity well, the current passes through the solution to the item attached to the cathode (negative side of the

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FIGURE 1. SCHEMATIC DIAGRAM OF ELECTROPLATING CELL

power supply). The circuit is thus complete. In electroplating the purpose of the circuit is to dissolve material from the anode and have it deposited ^{ON} ~~to~~ the cathode. For this purpose, one desires a solution or electrolyte which transmits current well. Ideally, material is removed from all the exterior of the anode and ^{PLATED} ~~played~~ onto the entire surface of the cathode.

In Electrochemical Deburring, the desire is to have metal leave from the edge of the part (i.e., burr to disappear), but not from the basic part itself. To accomplish this, one uses an electrolyte which does not conduct electricity well and one puts the negative pole adjacent to the edge of the area to be deburred (Figure 2). While the cell shown in Figure 2 will deburr, in actual practice one needs to force electrolyte between the part and the negative tool (Figure 3). This assures that the solution around the part is constantly replenished with fresh chemicals. In addition, the electrolyte flow drags away the by-product sludge of the chemical action. If left in place, this sludge would eventually cover the part and tool preventing effective electrical conduction. To provide consistent location of the negative pole and the part, the negative pole is designed as a locating tool.

The Electrochemical action is very rapid if correct voltage and current are available. In a typical application deburring is completed in 30 seconds. This makes this process one of the fastest burr removal processes in existence. While it was first applied to hard to reach intersections of holes and irregular intersections of features, it is now being used on external

FIGURE 2. SCHEMATIC OF SIMPLE ECD CELL

FIGURE 3. SCHEMATIC OF ELECTROCHEMICAL DEBURRING SYSTEM

edges because of its speed (currently up to 1,400 parts per hour).

The process has several other features which prove significant advantages:

- . It provides a smooth radius rather than a chamfer.
- . It is a process which exerts no mechanical forces on the part.
- . It does not affect part dimensions except at edges.
- . It can be utilized as a manual or a fully automated process.
- . It is a relatively low cost process.
- . It can be used to produce burr free shallow slots, grooves, or related depressions.

Figures 4 and 5 illustrate before and after photographs of parts which have been electrochemically deburred. The smooth radius produced ^{ASSURES}~~assumes~~ smooth flow of liquids or air over edges. This is an important criteria~~n~~ in the hydraulic, pneumatics, and fuel control industries.

The fact that the process produces no mechanical forces on the part allows it to be used on very thin sections without fear of distortion or part damage.

Most deburring processes change the dimensions of a part slightly. The basic size of parts deburred by ECD remain unaltered except at the very edge of the part

The fact that equipment can be purchased relatively inexpensively (as low as \$10,000 for small simple machine) or as sophisticated as desired make the process applicable to both

Figure 4. Hole Before ECD

Figure 5. Hole After ECD

job shops and high volume users. The only notable costs associated with the process are for a machine itself, operation labor, and the tools used for each part. The deburring medium (electrolyte) costs only pennies a week (in job shop situations).

One of the emerging ancillary uses of the process is to use the equipment to produce shallow (up to 0.030 inch) reliefs, pockets, or oil distribution channels in parts. In this application the process is a rapid machining process whose side benefit is burr-free edges. Figure 6 illustrates one such example.

THE ELEMENTS OF AN ECD SYSTEM

As shown in Figure 3 a working ECD system consists of,

- (1) The workpiece
- (2) Electrolyte
- (3) A tool
- (4) A power supply
- (5) A pump
- (6) Flow control and distribution devices
- (7) A reservoir
- (8) A filter

Workpiece

The workpiece can be any size or shape but it must be electrically conductive. This then limits the process to metallic parts. While burrs can be at any location on the part and can be any size, it is essential that the orientation of the

Figure 6. Oil Passageway Produced By ECD (reproduced with permission of Society of Manufacturing Engineers)

burr be consistent on every part. Thus if the tooling is designed to accomodate a burr ~~tharthen~~^{thrown} into the large diameter of two intersecting holes, the burr must always be in the large diameter. If it is not a short circuit will occur which can destroy or damage the part and the tool.

Some metals do not deburr well with the conventional electrolytes, but special electrolytes are available which will provide the necessary deburring. Sintered Tungsten is one such resistant metal.

Electrolytes

To provide a solution which concentrates the cutting edges near the tooling, salt solutions are used. Table salt (~~NaCl~~^{NaCl}) for example can be used in concentrations of 2 pounds per gallon of water. To provide better finishes or more uniform stock removal sodium nitrate (NaNO_3), sodium nitrite (NaNO_2) or potassium chloride (KCL) are used. In some cases a mixture of two or more of these electrolytes or a proprietary solution will be used.

Tooling

The single most important key to ~~the~~^{the} success of ECD is the tooling. The tool design affects loading and unloading time, deburring time, edge quality, and stray etching. Tool design affects the tool cost and therefore also the cost of deburring. It affects tool life and maintainability.

Since every feature deburred must have a tool designed for that feature some individuals have ignored ECD believing it to be too expensive. The fact is that today one can design

and make permanent or temporary tooling quickly and inexpensively. At least two machine manufacturers for example offer modular tools which are constructed from standard simple elements. Inexpensive tools for short run applications only require individuals who truly understand tooling needs.

Power Supply

Several power supply variations are available for use on ECD machines. Basically they output a low voltage high current direct current signal. As an example a small machine might have an output of 500 ^{amps} ~~amps~~ and 15 volts. The current required is in direct proportion to the size of the area to be deburred while the voltage determines the time ² ~~required~~ required to remove the burr. Empirical results indicate that one needs at least 10 Amps per inch of edge to be deburred. In actual practice the current requirements can be twice this and the relationship between removal time and voltage involves several other considerations.

Several different philosophies exist between different machine manufacturers on the optimum power supply design. Some prefer a pulsating "DC" current, while others prefer a straight DC signal. Some have continuously variable voltage while others increment in 0.5, 1.0, or 2.0 volt steps.

Flow Control and Distribution Devices

Simple plastic or rubber tubing are typically used to distribute electrolytes to the tool. Electrically energized valves automatically initiate and stop electrolyte flow for each part. On some machines temperature controls and/or salt concentration monitors

also interfere with the electrolyte system.

Filter

When the electrolyte reacts with the burr it produces hydrogen gas and a metal hydroxide. Iron hydroxide, for example, is produced when a ferrous part is deburred. This brown sludge must be filtered out of the solution to assure uniform metal removal on subsequent parts and to prevent its depositing on tools and parts.

Five types of filtration devices are used for this purpose.

- . Diatomaceous earth
- . Stainless steel reusable cartridge
- . In-line bag type filter
- . Centrifuge
- . Plate filter coated with diatomaceous earth

The diatomaceous earth filters require daily back flushing to clean out, and some storage for additional diatomaceous earth is required since this must be periodically replaced. Their advantage is that they can filter out particles as small as 1 micron while other filters typically only filter to 75 microns. (Smaller filter sizes are available however.) Diatomaceous earth is readily available in most large towns since it is used as a filter for swimming pools. Other filters either handle larger volumes of solution or provide easier clean out.

EQUIPMENT CONSIDERATIONS

When one attempts to purchase ECD equipment he discovers that all ECD equipment is basically similar and while standard models exist all models have a variety of options which tailor the machine to company needs. Major considerations that any

user must make include,

Can more than one tool be used at the same time?

Does each station warrant separate voltmeter or ammeters?

Is electrolyte flow or pressure gauges required?

Is electrolyte temperature control required?

Should the electrolyte be heated or cooled?

Is the electrolyte tank easily cleaned?

Is the filter type consistent with needs?

Is the filter easily cleanable?

Most, if not all, machines now have automatic short detectors and power shut down devices when shorts occur. All manufacturers know the necessity of using materials which will not corrode with long time salt exposure, although the approaches used in construction vary significantly. One recent purchaser defined 40 basic machine characteristics important to his application. The list in Table 1, while not that thorough, lists many of the features that one would want to consider.

SIDE EFFECTS

In evaluating any deburring process for precision parts one needs all the following information.

- . What materials will it work on
- . Will it change part size
- . Will it change part shape
- . What size of parts will it accommodate
- . What features of a part will it work on
- . What size of features will it accommodate
- . What will it do to precision finishes

TABLE 1. FEATURES TO CONSIDER WHEN SELECTING ECD EQUIPMENT

Machine Characteristics	Capacity of Various Machines		
	Machine		
	A	B	C
1. Power supply output (Amps.).			
2. Range of available voltage.			
3. Voltage increments.			
4. Air or water cooled power supply.			
5. Work station material.			
6. Designed for single or multiple station usage (Yes/No)			
7. Maximum clamp stroke (inch).			
8. Adjustable time delay for Electrolyte flow on (Yes/No)			
9. Ammeter/voltmeter for each station (Yes/No)			
10. General design concept suited to application (Yes/No)			
11. Filter type (Diatomaceous earth, stainless steel, inline bag, reuseable cartridge, centrifuge).			
12. Are gauges available for electrolyte flow (Yes/No)			
13. Automatic overload protection (Yes/No)			
14. Automatic cycle (Yes/No)			
15. Manual setup mode (Yes/No)			
16. Is workable height convenient for operator (Yes/No)			
17. How accurate is temperature control (°F.)			
18. What is recommended temperature range (°F.)			
19. What is reservoir capacity (gallons).			
20. Is conductivity controlled automatically (Yes/No)			
21. What input voltage is required (volts).			
22. Does drain system fit need (Yes/No)			
23. Is cooling water required (Yes/No)			
24. What floor space is required (___Sq. Ft.)			
25. Is tool mounting system adequate (Yes/No)			

- . How will it affect subsequent processes
- . What is the cycle time
- . What are the economics of the process
- . How does burr size affect the parameters in this list
- . How repeatable is the process

ECD has the distinct advantage as previously mentioned of working on all metals. If adequately tooled, the process will not change the part size. It will accommodate small parts and in some situations it can be used on parts weighing several tons by employing a portable wand tool. It works on all external and internal edges that the tooling is designed to accommodate. It can deburr holes 0.060 inch in diameter as well as those 5 inches in diameter. It has a fast cycle time and as shown later is economical in many more situations than used on.

The process has five characteristics that make it stand apart from other deburring techniques:

- . Stray machine^{ing} occurs
- . Stray etching occurs
- . Surface finishes are changed
- . Striations may occur
- . Discolored surfaces may occur

This process will change part size in the immediate vicinity of the burrⁿ edge (figure 7). This zone of size change typically will exist for 0.010 to 0.125 inch from the edges being deburred. If the part was improperly tooled, this ^effect could also be seen at other positions on the part.

Because ~~of~~ electrical fields and current flows are not

Figure 7.

Dimensional Change Near the Edge of a Miniature Gear

as totally controllable as one would like to have them, some etching of the surfaces can occur at a considerable distance from the part. As an example, figure 7 shows a 17-4 Ph stainless steel pinion gear which has been ECD'ed. While the edges have been deburred, the crest and flanks of the teeth have been etched (figure 8). In this seven second cycle the depth of etching was approximately 0.0002 inch. This etching is apparently the result of the fact that 17-4 Ph stainless steel is a martensitic steel and one phase of the martensite is susceptible to this stray current etching. This stray etching occurred in the middle of the part rather than at the edge. It appears that single phase metals such as ^{austenitic stainless} steels may not experience such etching.

If one evaluates the surface finish provided by ECD, he will find that it can result in finishes of less than 10 micro inches, and in many cases it can be as low as 2 micro inches.

As in any electrochemical process, one sometimes finds striations on the part (figure 9). Like tool ^{feed} ~~feed~~ marks these striations illustrate the path of electrolyte flow. Eliminating striations requires adjusting electrolyte flow such that turbulence is eliminated, gas bubbles are quickly removed from the surface and uniform insulation exists on the tool.

Most parts have some discoloration left on the part after ECD (figure 10). This discoloration is a function of the part material and electrolyte. For example, ^{6061-T6} ~~6061-T6~~ Aluminum in NaNO_3 has a white deposit left on it. On 17-4 Ph and 300 series stainless steel in the same solution a black discoloration can be seen. Some researchers believe these are hydroxides, others believe they are oxides, some think they ~~are~~ ^{are} carbon or graphite deposits drawn from

Figure 8. Stray Etching on 17-4 PH Stainless Steel Gear (same part as shown in Figure 7)

Figure 9A. Striations Left By ECD Process on 304 Stainless Steel

Figure 9B. Mottled Surface Left by ECD Process on 304 Stainless Steel

Figure 10. Discoloration Left By ECD on 304 Stainless Steel

the steel. Some believe that the discoloration is only the result of surface texture changes. This discoloration can be removed from many parts by brushing or by soaking in a strong alkaline solution when it is objectionable.

To individuals not accustomed to ECD, these side effects generally are a source of concern. Like any new process, one needs to ascertain if these effects are really detrimental or if they are in fact assets. The material removed at an edge can be an obvious clearance asset. The slight etching on the gear may be an asset in holding lubricant. The discoloration provides quickly discernable evidence that the part has been deburred by ECD.

PROCESS CONSIDERATIONS

The ECD process can be operated by individuals having a ~~very~~ limited educational background. In practice it involves setting up tooling, adjusting flow and voltage, pushing the automated cycle button, rinsing parts and related simple operations. In job shop applications involving crucial precision parts, it behooves the responsible engineer to have a good working knowledge of chemistry, electrochemistry, fluid flow, and tool design. Fortunately, the literature on electrochemistry is as readily available as is that of fluid flow.

While electrolyte effects have been defined in general, one will find that for critical parts experimentation will be required on electrolytes and tool design. For commercial parts, this experimentation may not be necessary.

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When evaluating ECD approaches one has to determine

1. What burrs should be removed by ECD
2. In which direction will the burrs project
3. How big are the burrs
4. Will stray machine^{ing} at the edge affect any critical features
5. What electrolyte works best for the part material
6. How much edge area or length must be deburred
7. What production rate is required
8. What total quantity of parts are to be run
9. What subsequent processes are required

In many situations the most economical approach may be to use ECD for burrs in hard to reach places and use conventional deburring processes for more accessible burrs. While ~~ECD~~^{ECD} can totally deburr parts, parts having many edges may require intricate tooling and parts having many inches of edges to deburr may require more current than available at the machine. The burrs must be consistently oriented in the same direction for this process to work. The choice of direction may affect tool design, removal time, and machine time.

Big burrs require a longer time to remove than smaller burrs. Figures 11 and 12 for example, present some typical data on size effects. Actual results, of course, depend on material, voltage, tool design, and electrolyte and electrolyte flow. For many parts, however, one will find that burr thickness at the root varies from 0.003 to 0.007 inch. This^U removal time is in the order of 10 to 20 seconds. Higher voltages and warmer

FIGURE 11. TYPICAL ECD BURR REMOVAL RATE FOR ALUMINUM ALLOYS

FIGURE 12. TYPICAL ECD BURR REMOVAL RATE FOR IRON BASE ALLOYS

electrolyte increase the burr removal rate. Providing a smaller gap between tool and part also reduces deburring time.

Any ECD machine has a limited current capacity. If one uses the rule of thumb that 10 amps are required for each inch of edge to be deburred then a 500 amp machine will have enough capacity for 50 inches. It is easy for an intricate part 2 inches by 3 inches by 1 inch to have 50 to 100 inches of edges. Thus, even though a part is small it may require the full current output. In addition, the rule of thumb frequently understates current needs. High production rates can be achieved with appropriate tooling, automation and by deburring two or more parts at a time.

ECONOMICS

As with most processes the choice of working parameters and tooling is an economic consideration. While little data is available in the literature on the economics of the process one can make some reasonable cost estimates using the following formula.

$$C = \frac{C_D + C_M + WC_P}{N} + \frac{(K_1 C_L + K_2 C_A)(1 + D_O)}{N} + \frac{C_T}{N_P} + \frac{C_S}{N_{P_1}} + \frac{C_F}{N_{P_2}} + \frac{A(F + H + L_i + I + G)}{H_y N}$$

For the first example assume that the machine is used in a Job Shop for short runs of precision parts. A \$16,000 machine is estimated to last 8 years with a use of 2000 hours per year. Direct labor costs are \$6.00 per hour and overhead costs are 20 percent of direct labor. Equipment maintenance is estimated at 10 percent

of depreciation costs and after deburring each part must be cleaned thoroughly manually. The cleaning for this example is estimated to require as much time as deburring. Fifty parts per hour will be run. The tool cost is \$500 and a total quantity of 500 parts will be run over the life of the tool (but only 100 parts will be run in this setup). The combined cost of electrolyte salts and water is estimated to be \$.50 per gallon. An estimated solution life is 500 parts per 50 gallons. The estimated time to set up and clean up is one hour.

For the indicated values the cost of deburring is \$1.37 per part (Table 2). While this is expensive compared to the cost of vibratory finishing or related processes it is not expensive if the feature being deburred could not be quickly deburred by another means. Consider hand deburring for example. If one assumes that hand deburring costs plus overhead are \$7.20 per hour and that no other costs are involved then \$1.40 represents 11 minutes of hand deburr effort. In other words, in a job shop situation such as described above ECD is the more economical process if hand deburring requires more than 11 minutes per part.

When one looks closely at the elements which are responsible for this cost, it is obvious that tool cost is the biggest factor (\$1 per part). The total labor costs of cleaning and deburring is 30 cents per part. If one could build an ECD tool for \$250 and eliminate one half of the cleaning time allocated in this example, then the cost of deburring would be 83 cents per part. For this example, power costs amount to less than 1 cent per part.

where:

C = Deburring cost per part.

C_D = Depreciation cost per hour = machine cost per operating hours.

C_M = Maintenance cost per hour of operation.

C_L = Labor cost per hour to run machine.

C_P = Cost of power used (\$ per kilowatt hour).

C_A = Cost of cleaning per hour after deburring (labor + material).

D_O = Overhead as percentage of labor rate.

N = Number of parts run per hour = n/t .

n = Number of parts run per cycle.

t = Time (hours) per cycle.

N_p = Total number of parts run.

N_{p1} = Number of parts run for a given quantity of solution or tool life.

C_T = Total tool cost.

C_S = Total cost of solution.

W = Power used, in kilowatts (1 hp = 0.75 kW).

C_F = Time (hours) for setup and cleanup.

N_{p2} = Number of parts run per setup.

H = Yearly heating costs for deburring area (\$/sq.ft./yr.)

L_i = Yearly cost of lighting for deburring area (\$/sq.ft./yr.)

I = Yearly insurance costs for deburring area (\$/sq.ft./yr.)

G = Any other yearly general overhead costs (\$/sq.ft./yr.)

H_y = Hours per year the deburring area is used.

A = Floor area of ~~base~~⁸ operation (sq.ft.).

F = Yearly floor space costs (\$/sq.ft./yr.).

K_1 = Percent of cycle time operator actually spends
controlling deburring operation.

K_2 = Percent of cycle time operator actually spends
controlling ~~deburring~~ cleaning operation.

TABLE 2
EXAMPLES OF UNIT DEBURRING COSTS

<u>COST ITEM</u>	<u>EXAMPLE NO. 1</u>	<u>EXAMPLE NO. 2</u>
C _D	1.00	3.00
C _M	0.10	0.30
C _L	6.00	6.00
C _P	0.04	0.04
C _A	6.50	7.00
C _T	\$500	3000
C _S	\$ 25	150
C _F	1.00	2.00
D _O	0.20	0.20
N	50	600
N _P	500	10,000
N _{P1}	500	10,000
N _{P2}	100	10,000
W	7.5	7.5
A	150	1000
F	5.00	5.00
H	1.40	1.40
L _i	0.50	0.50
I	0.10	0.10
G	1.00	1.00
H _Y	2000	2000
K ₂	1.0	0.5
K ₁	1.0	0.5
C	\$1.374	\$0.341

ECD's biggest cost advantage is in automated lines where hundreds of parts can be run per setup. Assume now an automated facility which costs 3 times as much as the one cited earlier and which takes 6 times more floor space. Assume ² production rate of 600 parts per hour and that the cleaning is automated such that one man can control both deburring and subsequent cleaning. Using the values shown in example 2 of Table 1, the cost per part would be 34 cents. In this instance also, the cost of the tool proves to be largest single cost element (\$0.30 per part). In a more highly automated facility in which several hundred thousand parts were deburred and multiple copies of the tools are used, the cost per part can be significantly less than the example cited. With appropriate conditions, it is possible to ECD parts for a cost less than \$0.10 per piece.

OTHER CONSIDERATIONS

In addition to selecting a machine, the new user of ECD must make several other considerations. On critical parts (Table 3), many will want to know that the services of qualified ECD tool designers are available. While the basic principles of ECD are well defined, the actual result of the process is greatly influenced by tool design. Until one has developed adequate experience, it is desirable to have a dependable source of design assistance. Similarly, in many instances, one will want a trained engineer or operator who understands electric currents, fluid flow, and metallurgy to develop the new applications. Critical parts ^{in a} ~~ma~~ job shop application require more than someone who can push buttons and who understands only the basics.

SUMMARY

ECD is not the answer to everyone's deburring problems. It is a high technology process when compared to tumbling processes. It requires more care, skill and knowledge than many of the older processes. It is not a mass finishing process. In contrast, ECD can deburr areas totally untouchable by other processes. It selectively works only in one area, and exerts no cutting forces which would distort thin sections. It is applicable to all metals and all sizes of burrs. Once established, the process can be controlled by unskilled help. With appropriate tool design, deburring costs can be significantly lower so quality is higher.

TABLE 3

CONSIDERATIONS IN AN ECD OPERATION

1. Machine requirements.
2. Tooling requirements.
3. Production rate.
4. Length of run.
5. Operator training.
6. Availability of Tool Design Support.
7. Machine maintenance.
8. Floor space requirements.
9. Utility requirements.
10. Effects on subsequent operations.
11. Process repeatability.
12. Engineering support.
13. Machine cost.
14. Tooling cost.
15. Cost per part.

EDITORS NOTE: For a list of ECD machine manufacturers,
see Pages 100-102 in the April 1978 Blue Book. Chemform of
Pompano Beach, Florida, should be added to that list.